

Figure 1:

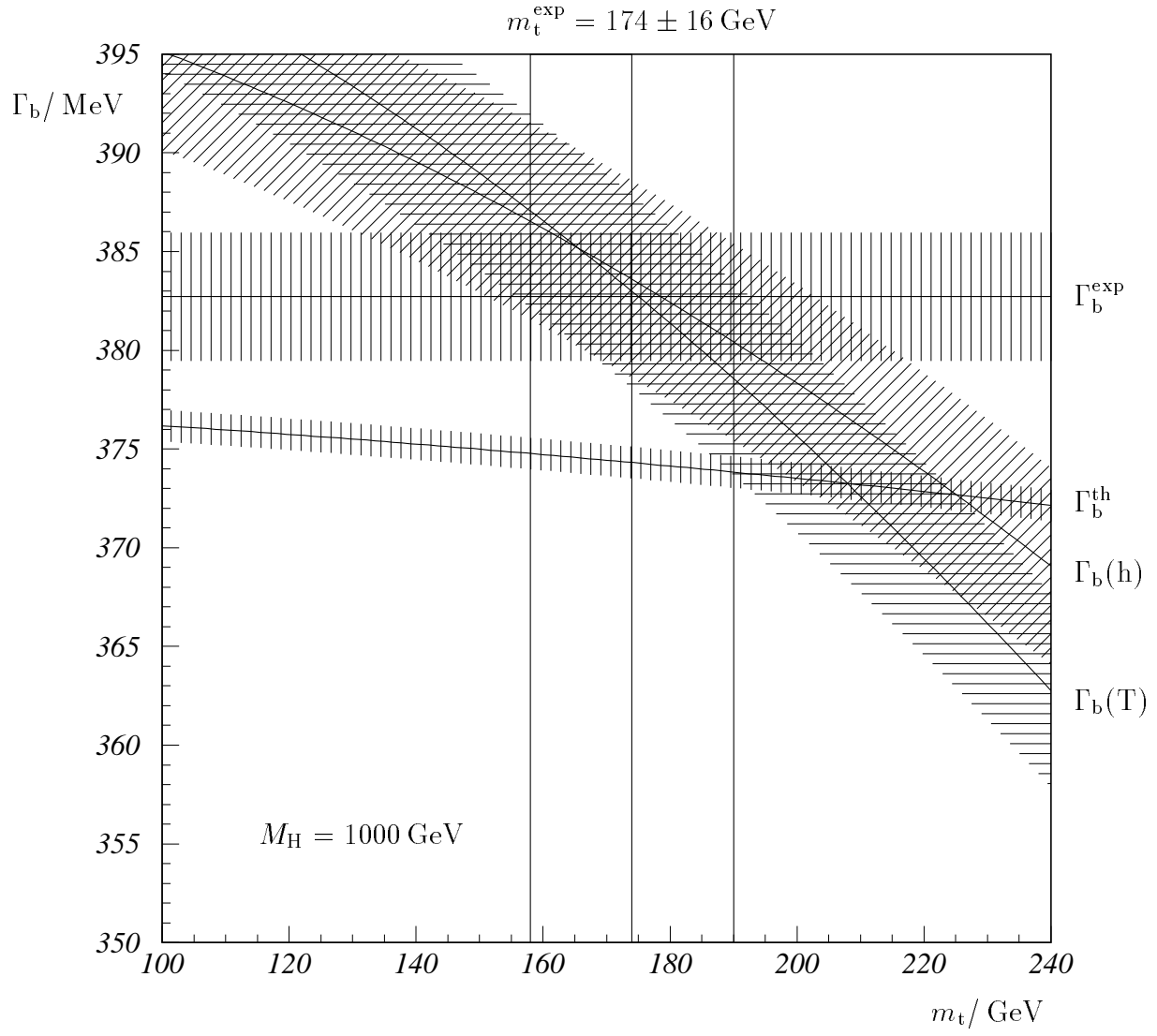


Figure 2:

A Remark on the $Z^0 \rightarrow b\bar{b}$ Width

D. Schildknecht

Department of Theoretical Physics

University of Bielefeld

Abstract

The $Z^0 \rightarrow b\bar{b}$ width, Γ_b , is analysed in conjunction with the total and hadronic Z^0 widths, Γ_T and Γ_h . Assuming, tentatively, that the present 2σ discrepancy in Γ_b will substantiate as time goes on, for large values of m_H it will be sufficient to modify the $Z^0 b\bar{b}$ vertex only. In contrast, for small values of m_H , the theoretical predictions for both the Z^0 width into light quarks and leptons as well as the $Z^0 \rightarrow b\bar{b}$ vertex will have to be modified.

The precise agreement (e.g. ref. [1]) between the predictions of the $SU(2)_L \times U(1)_Y$ electroweak theory [2] and the experimental data [3] is remarkable indeed. The only evidence for a possible discrepancy between theory and experiment was found in the value of the $Z^0 \rightarrow b\bar{b}$ width, which deviates from the theoretical prediction by approximately two standard deviations. The data are consistent with the width predicted for $Z^0 \rightarrow d\bar{d}$, and accordingly, they do not show the effect expected from the presence of the mass of the heavy top quark in the $Z^0 b\bar{b}$ vertex. As the discrepancy amounts to two standard deviations only, it may be wise to wait for further analysis of forthcoming data before reflecting too much on a possible theoretical explanation of it.

In the present note, nevertheless, we deal with the $Z^0 \rightarrow b\bar{b}$ width, restricting ourselves, however, to a few general comments on how the $Z^0 \rightarrow b\bar{b}$ “anomaly” could be accommodated in case it will substantiate and stand the test of time. We will briefly analyse the data on Γ_b in conjunction with the data on the total and hadronic Z^0 widths, Γ_T and Γ_h , respectively, in comparison with standard predictions. Our essential point consists of the observation that low and high values of the Higgs mass m_H , require different dominant modifications of the theory in order to accommodate the experimental value of Γ_b in conjunction with the experimental data for Γ_T and Γ_h .

Our analysis will be based on the experimental data presented at the Glasgow Conference [3],

$$\begin{aligned}
M_Z &= 91.1888 \pm 0.0044 GeV, \\
\Gamma_T &= 2497.4 \pm 3.8 MeV, \\
R &= \Gamma_h/\Gamma_l = 20.795 \pm 0.040, \\
\sigma_h &= \frac{12\pi\Gamma_l\Gamma_h}{M_Z^2\Gamma_T^2} = 41.49 \pm 0.12 nb.
\end{aligned} \tag{1}$$

From the values of R and σ_h one derives [1] *

$$\begin{aligned}
\Gamma_l &= 83.96 \pm 0.18 MeV, \\
\Gamma_h &= 1746 \pm 4 MeV,
\end{aligned} \tag{2}$$

* The correlation matrix between Γ_T, R and σ_h was taken into account.

and from the measured value of **

$$R_{bh} = \frac{\Gamma_b}{\Gamma_h} = 0.2192 \pm 0.0018, \quad (3)$$

one then obtains

$$\Gamma_b = 382.7 \pm 3.3 \text{ MeV}, \quad (4)$$

In what follows, we will compare the data for Γ_b in conjunction with the ones for Γ_T and Γ_h with standard theoretical predictions. All three of these quantities can be simultaneously analysed in a unified manner by first of all extracting the $Z^0 \rightarrow b\bar{b}$ width from the experimental total and hadronic widths, Γ_T^{exp} and Γ_h^{exp} , respectively, via

$$\Gamma_b(T) \equiv \Gamma_T^{exp} - 2 \left(\Gamma_u^{th} + \Gamma_d^{th} \right) - 3 \left(\Gamma_e^{th} + \Gamma_\nu^{th} \right) \quad (5)$$

and

$$\Gamma_b(h) \equiv \Gamma_h^{exp} - 2 \left(\Gamma_u^{th} + \Gamma_d^{th} \right). \quad (6)$$

In these formulae, $\Gamma_u^{th}, \Gamma_d^{th}$, etc. denote the (radiatively corrected) theoretical partial Z^0 widths for the $Z^0 \rightarrow u\bar{u}$, $Z^0 \rightarrow d\bar{d}$, etc. decays, while $\Gamma_b(T)$ and $\Gamma_b(h)$ refer to the partial widths for the $Z^0 \rightarrow b\bar{b}$ decay extracted from the total and hadronic Z^0 widths, Γ_T and Γ_h , respectively. It is evident that $\Gamma_b(T)$ and $\Gamma_b(h)$ in (5), (6), are “semi-experimental” quantities. They depend on the experimental data on the total and hadronic Z^0 widths, Γ_T^{exp} and Γ_h^{exp} , as well as the theoretical predictions for the other partial Z^0 widths which are subtracted on the right-hand-sides in (5), (6). Due to the strong dependence on the mass of the top quark, m_t (via the leading m_t^2 dependence), also $\Gamma_b(T)$ and $\Gamma_b(h)$ will be decreasing functions of m_t . In addition, $\Gamma_b(T)$ and $\Gamma_b(h)$ will depend on the Higgs mass, m_H , via $\ln m_H$.

Upon inserting the necessary theoretical partial widths into (5) and (6), we will compare $\Gamma_b(T)$ and $\Gamma_b(h)$ with the theoretical prediction for the $Z^0 \rightarrow b\bar{b}$ width, Γ_b^{th} , and with the experimental one, Γ_b^{exp} , and draw our conclusions.

** This value of R_{bh} is obtained [3] upon fixing $R_c \equiv \Gamma_c/\Gamma_h$ to its Standard Model value of $R_c = 0.171$.

The theoretical values for partial decay widths of the Z^0 into leptons and quarks are taken from our recent analysis of the electroweak precision data [1], based on

$$\begin{aligned}\alpha (M_Z^2)^{-1} &= 128.87 \pm 0.12, \\ G_\mu &= 1.16639(2) \cdot 10^{-5} GeV\end{aligned}\tag{7}$$

as well as M_Z from (1) and

$$\begin{aligned}\alpha_s &= 0.118 \pm 0.007, \\ m_b &= 4.5 GeV\end{aligned}\tag{8}$$

as input parameters.

The results of the present analysis are presented in figs. 1,2 for the two cases of a low value of $m_H = 100 GeV$ and a high value of $m_H = 1000 GeV$, respectively.

We first of all consider the case of $m_H = 100 GeV$ shown in fig. 1. From this figure one finds rough agreement of the $Z^0 \rightarrow b\bar{b}$ width extracted from the total and hadronic widths with the theoretical prediction, Γ_b^{th} , i.e.

$$\Gamma_b(T) \cong \Gamma_b(h) \cong \Gamma_b^{th}\tag{9}$$

for

$$\begin{aligned}m_t &\cong 175 \text{ GeV}, \\ m_H &\cong 100 \text{ GeV}.\end{aligned}\tag{10}$$

Obviously, the result (9), (10) is nothing else but the (known) consistency between theory and experiment in the total Z^0 width and in the hadronic Z^0 width, expressed, however, in terms of the $Z^0 \rightarrow b\bar{b}$ partial width. This consistency holds for values of $m_t \cong 175 \text{ GeV}$, the value favored by the results of the direct searches for the top quark [4.]. To remove the (indication of a small) discrepancy with Γ_b^{exp} in fig. 1, both, the theoretical prediction for $Z^0 \rightarrow b\bar{b}$ decay, Γ_b^{th} , as well as $\Gamma_b(T)$ and $\Gamma_b(h)$ will have to be modified, in order to keep the validity of (9). According to (5) and (6), this implies that the theoretical predictions for the Z^0 widths into light leptons and quarks will have to decrease. In summary, for small values of m_H , the data — always assuming that the minor discrepancy between theory and experiment visible at present will substantiate — require a modification of the theory which enlarges Γ_b^{th} and diminishes $\Gamma_u^{th}, \Gamma_d^{th}$, etc.

The situation (for $m_t \cong 175 \text{ GeV}$) is different in the case of the other extreme, a large mass of the Higgs boson of e.g. $m_H = 1000 \text{ GeV}$, as shown in fig. 2. In contrast to (9)

we now have

$$\Gamma_b(T) \cong \Gamma_b(h) \cong \Gamma_b^{exp} \quad (11)$$

for

$$\begin{aligned} m_t &\cong 175 \text{ GeV}, \\ m_H &\cong 1000 \text{ GeV}. \end{aligned} \quad (12)$$

For large values of m_H the (theoretical) values for the Z^0 widths into light quarks and leptons in (5), (6) are sufficiently suppressed to accommodate the present enhanced experimental value of Γ_b^{exp} within the total and hadronic widths, Γ_T^{exp} and Γ_h^{exp} . Accordingly, in this case, it will be sufficient to modify the $Z^0 b\bar{b}$ vertex to obtain consistency with the data for Γ_b^{exp} as well as Γ_T^{exp} and Γ_h^{exp} .

In conclusion, the presentation of the data given in figs. 1, 2 clearly illustrates the delicate interplay of the different experimental results and the parameters m_t and m_H . If the 2σ effect in Γ_b will stand the test of time, its theoretical explanation will have to discriminate between the low- m_H and the high- m_H options (always assuming $m_t \cong 175 \text{ GeV}$). For low values of m_H the theoretical predictions for the Z^0 widths into the light quarks and leptons as well as the $Z^0 \rightarrow b\bar{b}$ width will have to be modified. On the other hand, in the limit of large values of m_H , it will dominantly only be the theoretical prediction for the $Z^0 \rightarrow b\bar{b}$ vertex which must be changed.

Acknowledgement

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References

- [1] S. Dittmaier, D. Schildknecht, M. Kuroda, Bielefeld-preprint
BI-TP 94/62, hep-ph/9501404.
- [2] S.L. Glashow, Nucl.Phys.B **22** (1961) 579;
S. Weinberg, Phys.Rev.Lett. **19** (1967) 1264;
A. Salam, in: Elementary Particle Theory ed. N. Svartholm (Almqvist and Wiksell, 1968), p. 367.
- [3] D. Schaile, plenary talk given at the *27th International Conference of High Energy Physics*, Glasgow, July 1994,
LEP collaborations, preprint CERN/PPE/94-187.
- [4] F. Abe et al., CDF Collaboration, Phys.Rev. **D50** (1995) 2966.

Fig. 1:

In addition to Γ_b^{exp} , the figure shows Γ_b^{th} as a function of the mass of the top quark, m_t , as well as the “semi-experimental” quantities $\Gamma_b(T)$ and $\Gamma_b(h)$ obtained from the total and hadronic Z^0 widths, Γ_T and Γ_h , by subtracting the theoretical predictions for the Z^0 decay widths into light quarks and leptons. The value of $m_t = 174 \pm 16 \text{ GeV}$ preferred by the CDF searches is also indicated. For the theoretical prediction for Γ_b^{th} and for $\Gamma_b(T)$ and $\Gamma_b(h)$ a Higgs-boson of mass of $m_H = 100 \text{ GeV}$ was adopted. The error in Γ_b^{th} is due to the experimental error in α_s . This error is also taken into account in $\Gamma_b(T)$ and $\Gamma_b(h)$.

Fig 2.:

As fig 1, but for $m_H = 1000 \text{ GeV}$.